Unit 1

Basics of Electricity and Electronics

Introduction

Electricity holds an important place in modern society. Almost all appliances used these days work on electricity. Even the automobile industry has launched cars, which run on electricity instead of fuel. If the power supply of a city breaks down, hospitals, hostels, offices, schools, food storage plants, banks and shops will also stop working.

Electricity is defined as the flow of electric charge. Where do the charges come from? How do they move? Where do they move? To explain what is electricity, we need to go beyond the matter and molecules to atoms that make everything we interact with. It is important to understand the concept of electricity for installation and troubleshooting of electrical appliances.

Fig. 1.1(a) A wireman monitoring a control panel


Fig. 1.1(b) A lineman repairing electric fault

Electric elements include controlled and uncontrolled sources of energy, resistors, capacitors and inductors. An electric circuit should be designed in such a manner that it is able to perform the desired functions. Analysis of electric circuits refer to computations required to determine unknown quantities, such as voltage, current and power associated with one or more elements in the circuit. As shown in Figs 1.1(a) and 1.1(b), to work in the area

of electrical engineering, a person should have the basic knowledge of electric circuit analysis and laws. Other systems like mechanical, hydraulic, thermal, magnetic and power are easy to analyse and model by a circuit. To learn how to analyse the models of these systems, first one needs to learn the techniques of circuit analysis. This Unit briefly discusses some of the basic circuit elements and laws that will help students get a background of the subject. The students can, hence, apply their knowledge to design, build and demonstrate their own circuits.

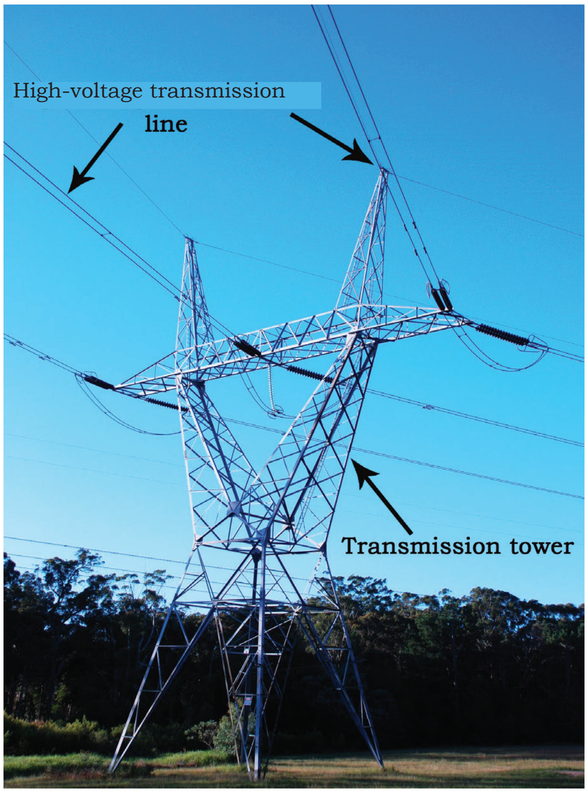

Fig. 1.2 Transmission tower

Fig. 1.3 Natural discharge of charge

Electricity

Electricity is a set of physical phenomena associated with the presence and flow of electric charge. Electricity gives a wide variety of well-known effects, such as lightning, static electricity, electromagnetic induction and electrical current. In addition, electricity permits the creation and reception of electromagnetic radiation, such as radio waves. Electrical energy can be easily transferred from one location to another with minimum loss through a transmission tower (Fig. 1.2).

Source of electricity

Energy is the driving force for the universe. It is a quantitative property of a system. Natural electricity is generated by thunderstorm and lightning as shown in Fig. 1.3.

Energy transformation

There are different forms of energy, such as thermal energy, hydel energy, solar energy, wind energy, nuclear energy, etc. According to the law of conservation of energy, energy can neither be created nor destroyed. It can only change its form. One form of energy can be

converted to another. Electrical energy can be generated by transforming several type of energies.

Nuclear	→	Electrical
Chemical	→	Electrical
Hydel	→	Electrical
Thermal	→	Electrical
Solar	→	Electrical
Wind	→	Electrical

Fig 1.4 shows various power stations, such as solar, thermal, hydel and wind. Figs. 1.5(a) and (b) show how electrical energy can be generated and distributed from a hydel and thermal power plant.

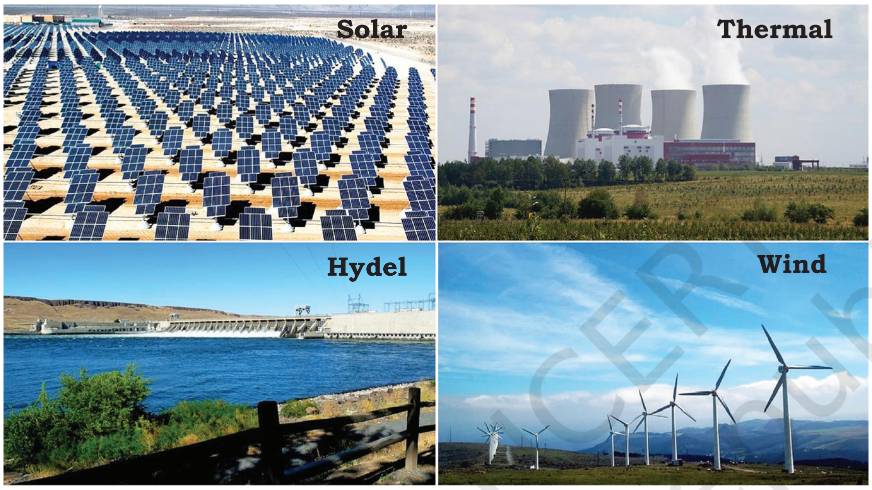

Fig. 1.4 Different type of power stations

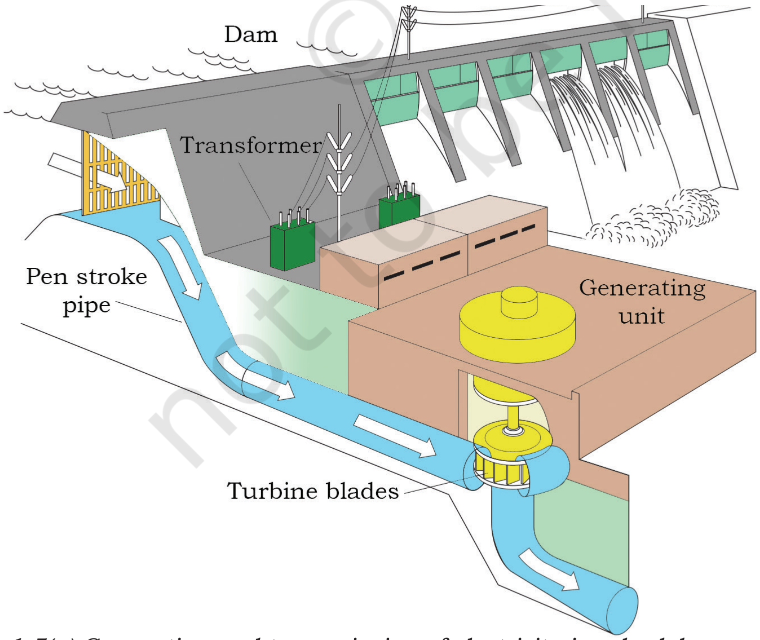

Fig. 1.5(a) Generation and transmission of electricity in a hydel power plant

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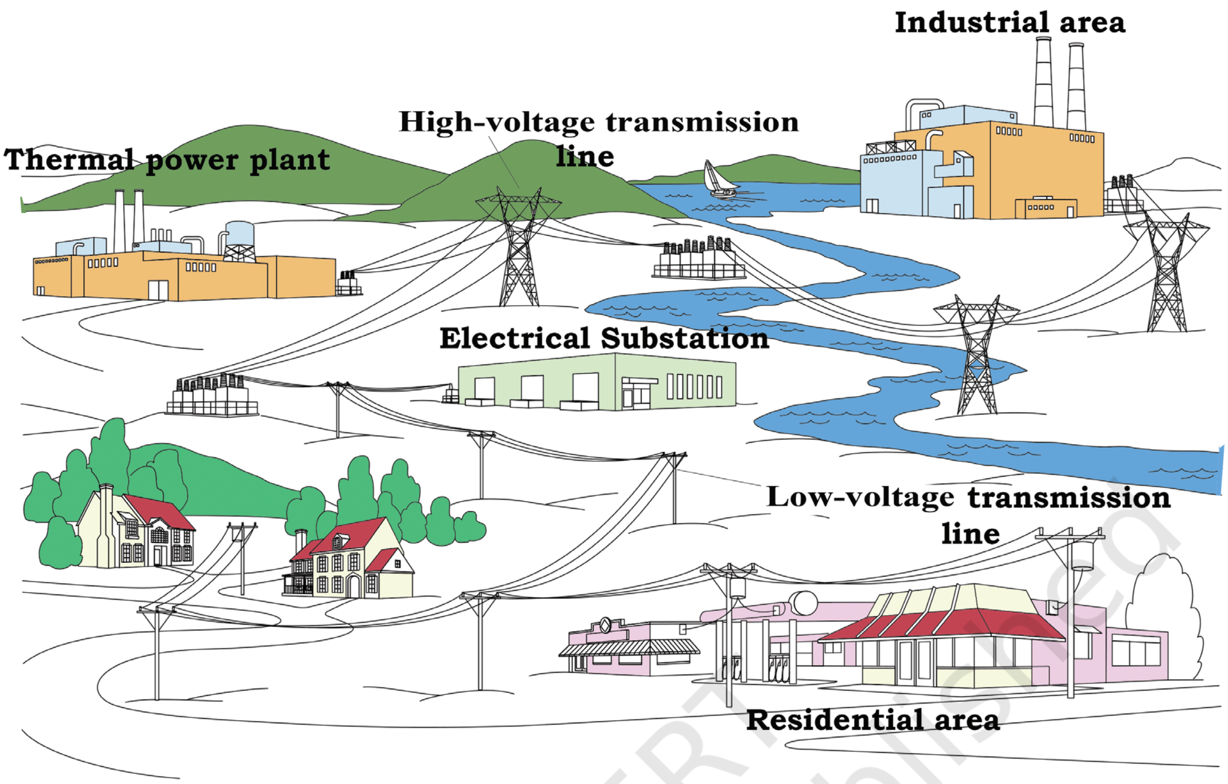

Fig. 1.5(b) Generation, transmission and distribution of electricity in a thermal power plant

Energy foundation

To understand electricity, we need to know about atoms. Everything in the universe solid, liquid or gas is made of atoms. An atom is the smallest constituent unit of matter. Atoms are so small that millions of them can fit on the head of a pin.

Atom

The centre of an atom is called the 'nucleus'. Atoms consist of subatomic particles — protons, neutrons and electrons. The protons and neutrons are very small, and electrons are even smaller. Electrons spin around the nucleus in shells at a great distance from the nucleus. Protons carry positive (+) charge, electrons carry negative (–) charge, and neutrons are neutral. The positive charge of the protons is equal to the negative charge of the electrons. Electrons move in their orbit around the nucleus. The positively charged protons

attract negatively charged electrons, and hence, hold the atomic structure as shown in Fig. 1.6.

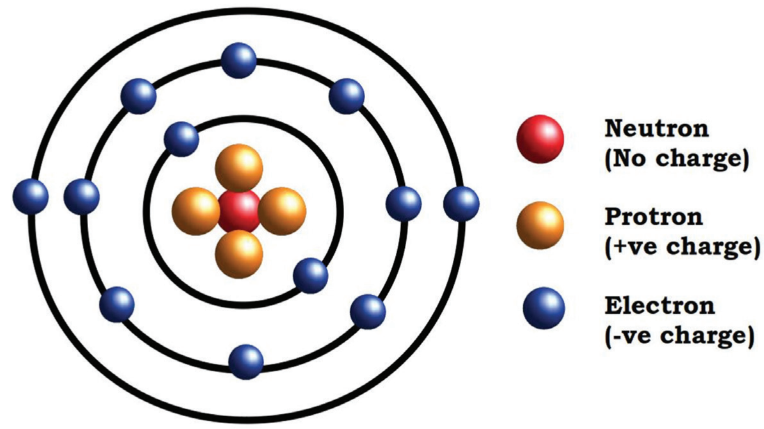

Fig.1.6 Atomic structure

Charge

Electric charge is the basic property of electrons, protons and other subatomic particles. Opposite charges attract each other and similar charges repel each other. This makes electrons and protons stick together to form atoms. One foundational unit of electrical measurement is 'coulomb', which measures electric charge proportional to the number of electrons in an imbalanced state. It was discovered by Charles-Augustine de Coulomb.

One coulomb of charge is equal to 6×10^{18} (6,250,000,000,000,000,000) electrons. The symbol for electric charge quantity is capital letter 'Q' and the unit of coulomb is abbreviated by the capital letter 'C'.

Flow of charge inside a wire: Free electrons randomly move from one point to another inside a conductor. Due to this random flow, the net electric charge of a conductor is zero. When an external power source is attached, the net flow of electrons is in one direction. This movement of electrons results in current. If there is a current of 1 ampere passing through a wire, it theoretically means that 6×10^{18} electrons are moving from one point to another in 1 second as shown in Fig. 1.7.

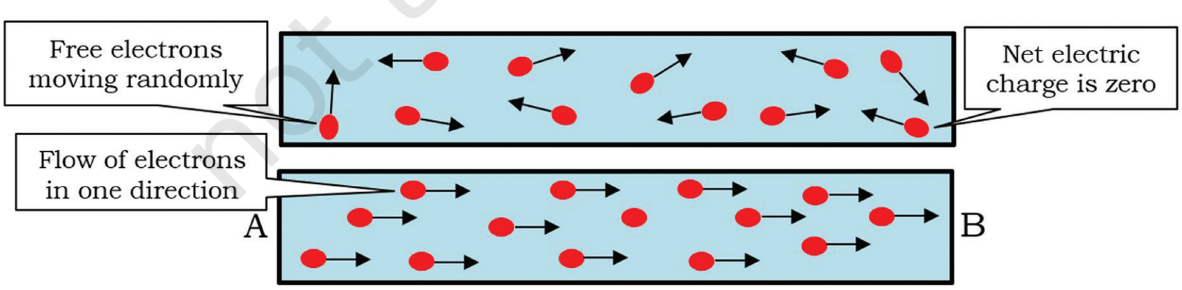

Fig.1.7 Flow of electrons

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Conductors and insulators

When electrons move, current is generated. As in case of a piece of wire, the electrons are passed from atom to atom, creating electrical current from one end to another.

Conductors

The material, in which electrons are loosely held, can move easily. These are called conductors. Metals like copper, aluminium and steel are good conductors of electricity.

Insulators

The material, which holds electrons tightly and do not allow movement of electrons through them, are called insulators. Rubber, plastic, cloth, glass and dry air are good insulators and have high resistance.

Types of electricity

Electricity can be classified as:

1. Static electricity
2. Dynamic or current electricity

Static electricity

Static electricity is the result of imbalance between negative and positive charges in an object. When electrons do not move from one point to another, it is called static electricity. Static electricity exists in the form of direct current (DC). Energy stored in an electric cell or battery is an example of static electricity.

Dynamic or current electricity

Current electricity flows through wires or other conductors and transmits energy to devices. The flow of electricity is possible only because of the flow of charged particles, i.e., electrons. When electrons are in motion, the electricity, thus, generated is called dynamic or current. Dynamic electricity exists in the form of alternate current (AC). Dynamic electricity cannot be stored. It has to be converted to static electricity for storing it. Current flowing through electrical wire and electrical AC generator are examples of dynamic electricity.

Assignment 1

- Discuss the different sources of electricity, and also renewable and non-renewable sources of electricity.
- Prepare a data sheet, in which electricity generating capacity of five hydel power generating stations, are mentioned.
- List the name of top five thermal power plants in India as per their electricity generating capacity.

Notes

Electrical quantities

Current, voltage and resistance are the three basic building blocks of electricity and electronics and are known as 'electrical quantities'. One cannot see energy flowing through a wire or voltage of a battery with the naked eye.

An electric circuit is formed when a conductive path is created to allow free electrons to move continuously. This continuous movement of free electrons through the conductors of a circuit is called 'current', and is often referred to in terms of 'flow', just like the flow of some liquid through a hollow pipe.

The force motivating electrons to 'flow' in a circuit is called 'voltage'. Voltage is the specific measure of potential energy that is always relative between two points.

Free electrons tend to move through conductors with some degree of friction or opposition to motion. This opposition to motion is called 'resistance'. The amount of current in a circuit depends on the amount of voltage available to motivate the electrons, and also the amount of resistance in the circuit to oppose electron flow.

Table 1.1 Standard units of measurement for current, voltage and resistance

Quantity	Symbol	Unit of measurement	Unit abbreviation
Current	I	Ampere	A
Voltage	V	Volt	V
Resistance	R	Ohm	Ω

The symbol given for each quantity is the standard alphabetical letter used to represent that quantity in an algebraic equation. Each unit of measurement is named


Alessandro Volta (1745–1827)


Andre M. Ampere (1775–1836)


Georg Simon Ohm (1789–1854)

Fig. 1.8 Famous scientists

after a famous scientist. Amp after Frenchman **Andre M. Ampere**, volt after Italian **Alessandro Volta** and Ohm after German **Georg Simon Ohm** (Fig. 1.8).

When these quantities are in DC form, they are represented by capital letters, i.e., 'R' for resistance and 'V' for voltage, which are both self-explanatory, whereas, 'I' stands for current.

Voltage

Voltage is the potential difference between two points. Voltage is also the amount of work required to move one coulomb charge from one point to another. Mathematically, it can be written as:

$V=W/Q$

where,

'V' is the voltage

'W' is the work in joule

'Q' is the charge in coulomb

In an electric circuit, battery is used as an electric potential. Battery is one of the sources of voltage in an electric circuit. Inside a battery, chemical reactions provide the energy needed to flow electrons from negative to positive terminal.

When voltage is applied in an electric circuit, negatively charged particles are pulled towards higher voltages, whereas, positively charged particles are pulled towards lower voltages. Therefore, current in a wire or resistor always flows from higher to lower voltage.

A voltmeter is used to measure voltage (or potential difference) between two points in a system. The value of voltage is measured in volt or joules per coulomb. The symbolic representation of voltage is **'V'** or **'v'**. **'V'** is for DC voltage and **'v'** for AC voltage.

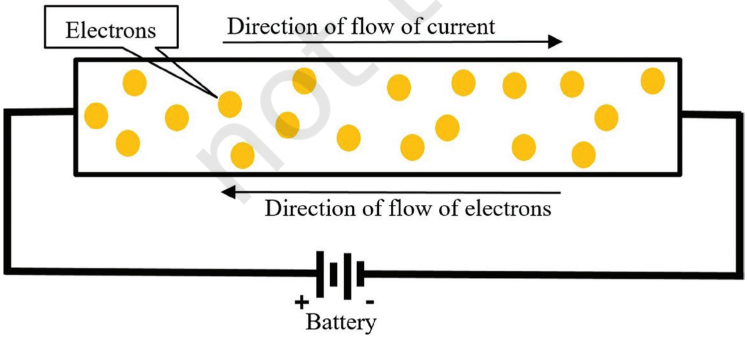


Fig.1.9 Flow of electrons on application of DC supply

Example 1: When 1 joule of work is done to move 1 coulomb charge from one point to another, the potential difference between the two points is said to be one volt.

Current

Electric charge, often called current, is the flow of electrons. These electrons carry charge. The electrons flow from one place to another. Moving electrons generate more charge. The amount of charge with electrons flowing from one place to another is called electric current (Fig. 1.12). The unit of measuring current is ampere (A). The symbolic representation of current is 'I' or 'i'. 'I' is for DC current and 'i' for AC current. Mathematically, it can be written as

$$I = Q/t$$

where,

'I' is the current
'Q' is the amount of charge in coulombs
't' is the time in seconds

Note: Coulomb is the unit of charge.

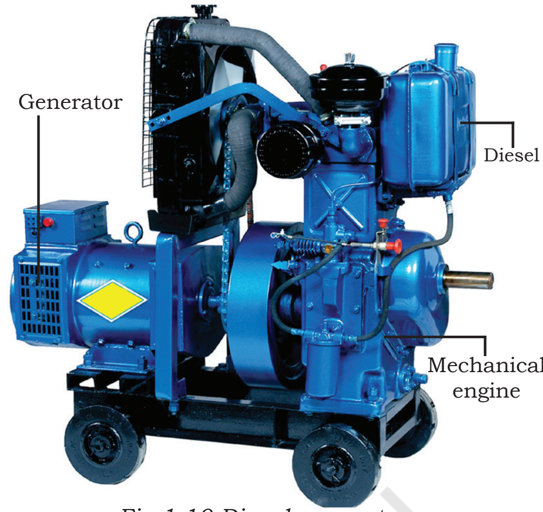


Fig.1.10 Diesel generator

Fig.1.11 Battery as a source of DC voltage

Example 2: If 1 coulomb charge passes through a point in 1 second, it will represent 1 ampere current. Conventionally, the direction of current is taken as opposite to the flow of electrons.

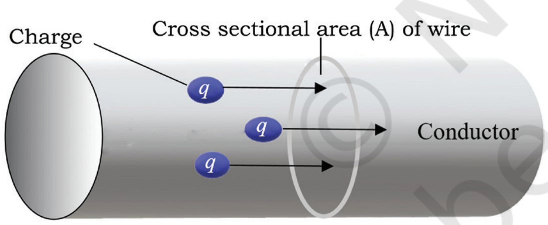


Fig. 1.12 Flow of charge through cross sectional area 'A'

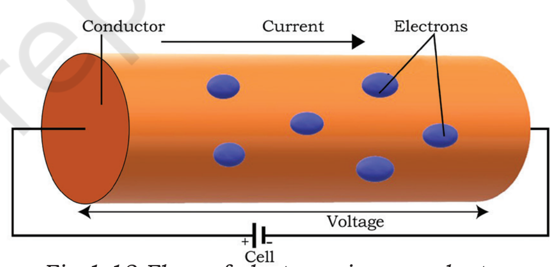


Fig.1.13 Flow of electrons in a conductor

Classification of current

Depending on the movement of electrons in an electric circuit, current can be classified as

1. Direct current (DC)
2. Alternating current (AC)

Direct current

It is unidirectional in nature, i.e., movement of electrons takes place only in one direction. This means that the

current flows only in one direction. DC voltage source (like batteries and cells) produces direct current. Direct current is used in a wall clock, remote control, vehicles, automobile, cell phone, etc.

Alternating current

It is bidirectional in nature. The movement of electrons takes place in two directions, i.e, current flows in two directions. AC voltage sources (like AC generator) produce alternating current. Hydel power plants, thermal power plants, etc., are examples of alternating voltage sources. Alternating current is used in ceiling fan, cooler, washing machine, etc. In India, standard AC generating frequency (f) of alternating current is 50 hertz.

Frequency can be defined as 'the number of cycles in one second'. Point A to point B represents one cycle. Hertz (Hz) is the unit of frequency.

Example 3: 50 Hz represents 50 cycles in 1 second.

The main difference between AC and DC current is the direction of the flow of electrons. In alternating current (AC), the movement of electric charge periodically reverses direction. In direct current (DC), the flow of electric charge is only in one direction.

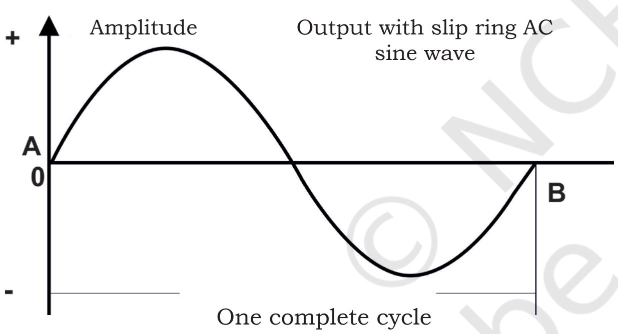


Fig. 1.14 Cycle of AC signal

The usual wave form of an AC power circuit is a sine wave (Fig. 1.14). In certain applications, different wave forms are used, such as triangular or square waves. Audio and radio signals carried on electrical wires are also examples of alternating current.

Resistance

In conductors, electrons are loosely held and can move easily. In insulators, electrons are tightly bound to their atoms and do not move easily. A high voltage electromotive force (EMF) is required to move the electrons in an insulating material. Thus, the insulator holds the electricity safely. On the other hand, a small voltage or EMF is required to move the electrons in any

conductor. In conductors, the resistance is low, while in insulators, it is high.

As the name suggests, a resistor resists the flow of electrons, and hence, electric current in the circuit. Conceptually, resistance controls the flow of electric current. Electrical conductance, which easily passes current, is opposite the quantity to electrical resistance. Resistance is represented by the symbol 'R'. The SI unit of electrical resistance is Ohm (Ω), while electrical conductance is measured in siemens (S).

Electric power

Electric power is the rate at which electric energy is transferred by a circuit. Electric power, is the rate of doing work, i.e., amount of work done in one second. Power is represented by the symbol 'P'. The SI unit of power is watt (W), which is equal to one joule per second. It is named after Scottish inventor James Watt (1736–1819).

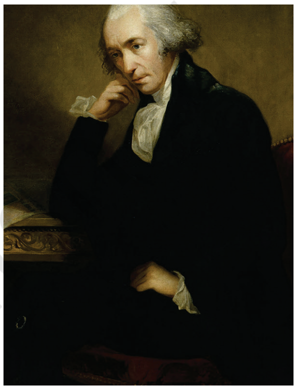


Fig. 1.15 James Watt (1736–1819)

Electric horsepower (hp) is another unit of measuring power. It is equal to 746 watt. It is slightly higher than mechanical horsepower, which is 745.7 joules per second.

The electric power in watt produced by an electric current I consisting of a charge of Q coulombs every t seconds passing through an electric potential (voltage) difference of V is:

P = Work done per unit time = $QV/t = V \times I$

Where,

Q is electric charge in coulombs

't' is time in seconds

'I' is electric current in ampere

'V' is electric potential or voltage in volts

$P=W/t$ or $P=I^2R$

Where,

'W' is the work done in joules

't' is the time in seconds

Power can also be defined in terms of current and voltage, i.e., product of voltage and current results in power. Watt is the measure of energy flow. Since watt is a very small unit of power, we need a much larger unit like kilowatt, which is equal to 1000 watts, in actual practice.

Fig. 1.16 Domestic Efficiency Lighting Programme (DELP) 9 Watt LED

Since, the product of power and time gives electrical energy, therefore, the unit of electrical energy is watt hour or kilowatt hour. One watt hour of energy is consumed when 1 watt of power is used for 1 hour. The commercial unit of electric energy is kilowatt hour (kWh).

$$1\text{kWh} = 1000 \text{ watt} \times 3600 \text{ second}$$
$$= 3.6 \times 10^{6} \text{ watt second or } 3.6 \times 10^{6} \text{ joule}$$

For example, the power of this LED is 9 watt (Fig. 1.16). This 9 watt defines it will do 9 joules of work in 1 second. LED is the replacement of compact fluorescent lamp (CFL). LEDs are more efficient than CFLs.

Assignment 2

A 100 watt electric bulb is lighted for two hours daily and four 40 watt bulbs are lighted for four hours daily. Calculate the energy consumed (in kWh) in 30 days.

Power factor

In an AC circuit, various components are connected together, such as resistor, inductor and capacitor. These components consume power. When voltage is applied to an inductor, it opposes the change in current. Current builds up more slowly than voltage, lagging in time and phase. In this way, it can be stated that current lags voltage. In case of a capacitor, voltage is directly proportional to the charge on it. Current must lead the voltage in time and phase to conduct charge on the plates and raise the voltage. When inductor or capacitor is involved in an AC circuit, current and voltage do not peak at the same time. The fraction of period difference between the peaks, expressed in degrees, is called 'phase difference'. The phase difference is <= 90 degrees. Because of this phase difference in voltage and current, power in capacitor and inductor will be minimum. In other words, it can be said that this power will be radiated by the circuit. This power is known as 'reactive power'.

Know more...

The Government of India launched the National Programme for LED-based Home and Street Lighting in New Delhi for energy conservation by reducing its consumption. Along with this programme, the government also launched a scheme for Light Emitting Diode (LED) bulb distribution under the Domestic Efficient Lighting Programme (DELP) to enable consumers in Delhi to register requests for LED bulbs under DELP.

In case of resistor, both current and voltage are in the phase. Therefore, power applied to the resistor gets utilised. This power is called 'real' or 'true' power. Combination of true and reactive power is called apparent power.

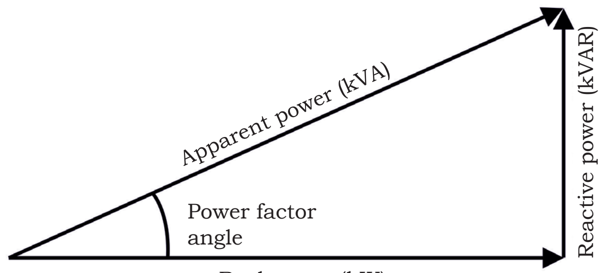


Fig. 1.17 Power factor triangle

Power factor is the ratio of real power to apparent power. Value of power factor varies from 0 to 1. It is denoted by cos Ø.

Power factor = Real power/Apparent power

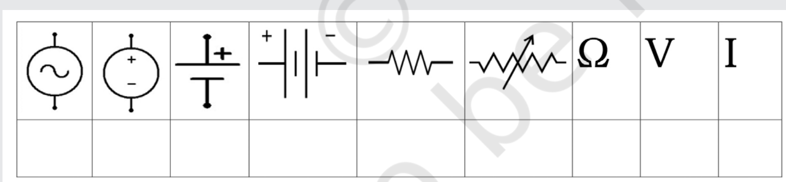
Referring to Fig. 1.17, it can be observed that as reactive power starts reducing, real and apparent power become equal. When real power and apparent power become equal, it means that the AC circuit is resistive in nature, i.e., it will only have a resistive component in the circuit. Hence, it can be summarised that reactive power due to capacitor and inductor will not get utilised by the circuit.

Apparent power is the total power given to the circuit, whereas, reactive power is the unutilised power, and real power is the power utilised by the circuit.

Assignment 3

Practical Exercise 1

Identify the following symbols and write down their names.



Practical Exercise 2

Draw the circuit as shown in Fig. 1 and indicate voltage, current, resistance and power.

Material required

Battery of 9V, fixed resistor of 3 Ohm, bulb or LED of 5 watt

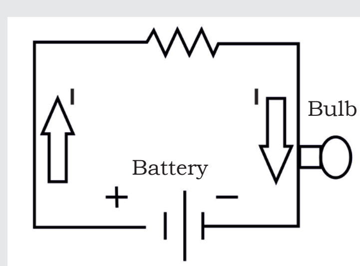


Fig. 1

Practical Exercise 3

Identify live, neutral and earth on power socket as shown in Fig. 2.

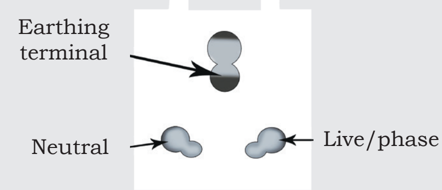


Fig. 2 A 3-pin socket

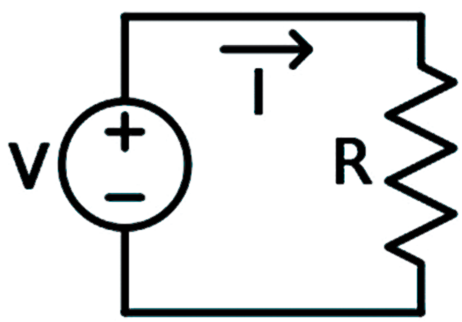


Fig.1.18 Basic electric circuit

Basic electric circuit

An electrical circuit supplies electricity to an electrical device. This device is called 'load'. Before the load operates, electricity must have a complete path from the source to the load and back to the source.

This path for electricity is called 'circuit'. An electric circuit is an interconnection of electric components so that electric charge is made to flow along a closed path (circuit), usually, to perform some useful task. In Fig. 1.18, the voltage source V on the left drives a current I around the circuit, delivering electrical energy into the resistor R. From the resistor, the current returns to the source, completing the circuit.

The components in an electric circuit include resistor, capacitor, inductor, semiconductor, integrated circuit, etc. Electronic circuits contain active components, usually, semiconductors. The simplest electric components are passive in nature. They may temporarily store energy. They do not contain any source of energy. The components of a circuit can be active or passive.

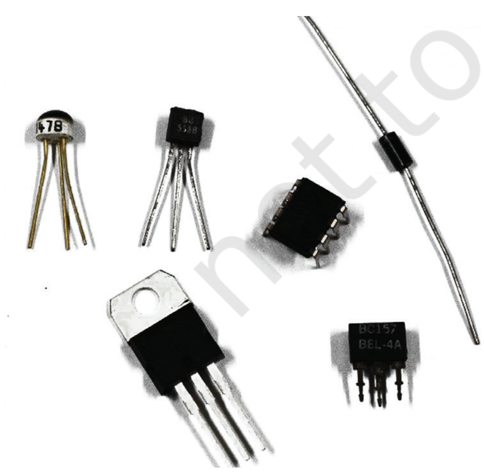


Fig.1.19 Active components

Active and passive components

There are two classes of electronic components—active and passive.

Active components

They produce energy in the form of voltage or current. These components require an external

source for operation. Some of the common examples of active components are diode and transistors. If we connect a diode to a circuit, and then, connect this circuit to the supply voltage, the diode will not conduct the current until the supply voltage reaches 0.3 (in case of Germanium) or 0.7V (in case of Silicon).

Passive components

They do not produce energy in the form of voltage or current. These components do not require an external source for operation. Some of the common examples of passive components are resistor, capacitor, inductor, etc. Like a diode, a resistor does not require 0.3 or 0.7 V, i.e., when we connect it to the supply voltage, it starts work automatically without using a specific voltage.

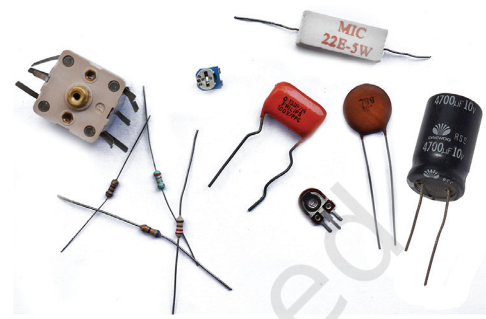


Fig.1.20 Passive components

In simple words, active components are energy donors and passive components are energy acceptors.

Open and closed circuit

A circuit is a closed path or loop around which electric current flows. If the circuit is complete, it is called 'closed' and the device receives power to work. If this path is broken, the circuit is said to be 'open' and the device does not work [Figs. 1.21 (a) and (b)].

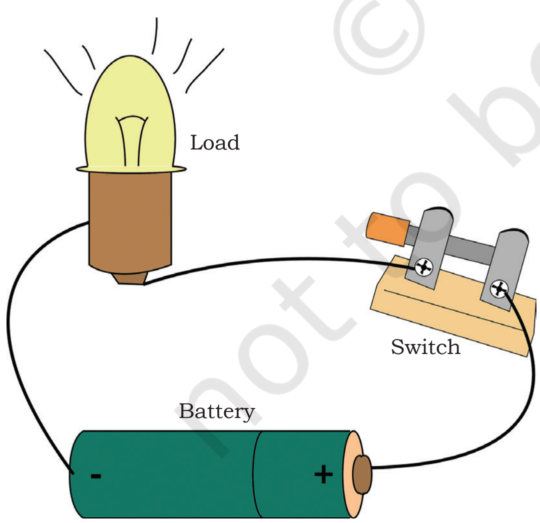


Fig.1.21(a) Closed circuit

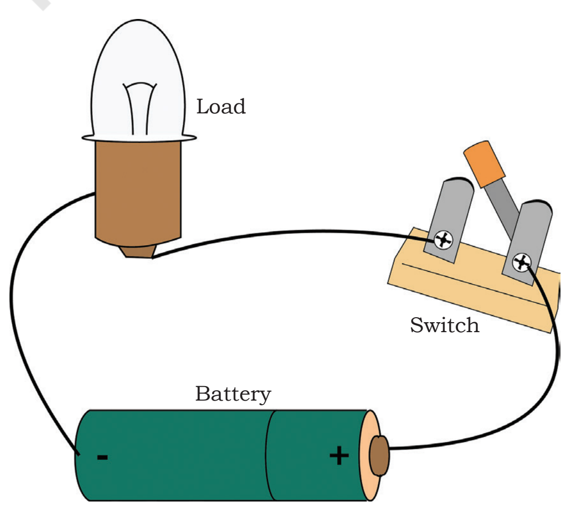


Fig.1.21(b) Open circuit

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Practical Exercise 4

Analysis of open and closed circuit—Prepare the circuit to glow the lamp as shown in Figs. 1 and 2.

Material required

9-volt battery, connecting wire, resistor, lamp, wire stripper, wire cutter and switch

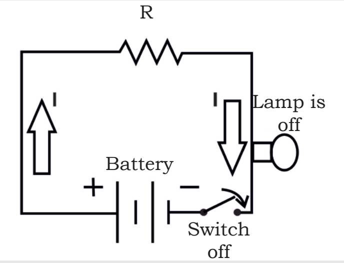


Fig.1 Open circuit

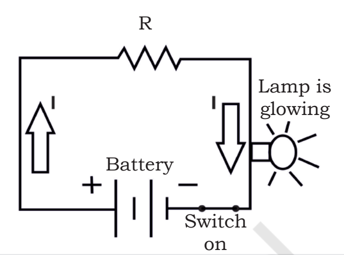


Fig. 2 Closed circuit

Procedure

Follow the steps given below to form a circuit.

1. Take a battery and identify its positive and negative terminals.
2. Take a wire. Cut it using a wire cutter and strip the insulation using a wire stripper.
3. Connect the wire to the positive and negative terminals of the battery.
4. Connect a resistor to the wire, which is connected to the positive terminal of the battery.
5. Connect the other terminal of the resistor to one of the terminals of the lamp.
6. Connect the other terminal of the lamp to one of the terminals of the switch.
7. Connect the other terminal of the switch to the wire, which is connected to the negative terminal of the battery.

Observation

When the switch is turned 'on', the lamp starts glowing.

Practical Exercise 5

Construct a test lamp.

Material required

1 bulb, 1 bulb holder, wire, wire cutter, wire stripper and plug

Circuit diagram

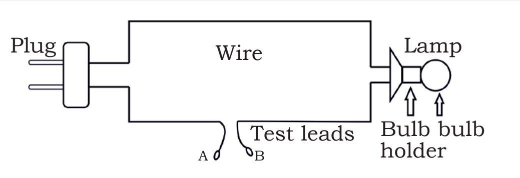


Fig.1 Circuit diagram for test lamp

Procedure

1. Cut the wire into two pieces, each one metre long, using a wire cutter.
2. Now, you have two pieces of wire. Strip the insulation of the wire terminals.
3. Fix the bulb holder using one end of the two pieces of wires and install a light bulb onto the holder.
4. The other two ends of the wires are free. Fix a two-pin plug on those free pairs of wires. It means you can light up the bulb if you put a two-pin plug in a live two-pin socket.
5. Check the continuity of the test lamp, i.e., see if the bulb turns on when the plug is inserted in a live two-pin socket.
6. Now, pull out the plug from the socket.
7. Finally, you need to slice one of the wires in the middle and remove insulation from each of the cut ends for half-an-inch so that the bare copper is clearly visible.
8. Your test lamp is ready for experiment. Always use a cap to cover the bare copper wire to avoid accidents.

NOTES

Series and parallel circuit

Electronic circuits are arranged in many ways. Circuits are named on the basis of how the components are connected. The two simplest form of circuits are series and parallel.

Series circuit

In a series circuit, electric loads are connected along a single path. Therefore, the current flowing across the path will remain the same. Since, there is only one path for the electrical current to flow, all electric load in the circuit will stop working if a wire is cut or a switch is turned on. If a battery connected to the circuit has insufficient charge or energy, there will be insufficient current supply in the circuit. In this case, the battery needs to be replaced. Adding two batteries in the series may also solve the problem. In the series circuit, the arrows show the flow of current.

A series circuit or 'series-connected circuit' is a circuit having just one current path. Fig. 1.22 (a) is an example of a 'series circuit', in which a

battery of constant potential difference V (volt), and three resistances (R_1, R_2 and R_3) are all connected in series.

Since a series circuit has just one current path, all components in it carry the same current I.

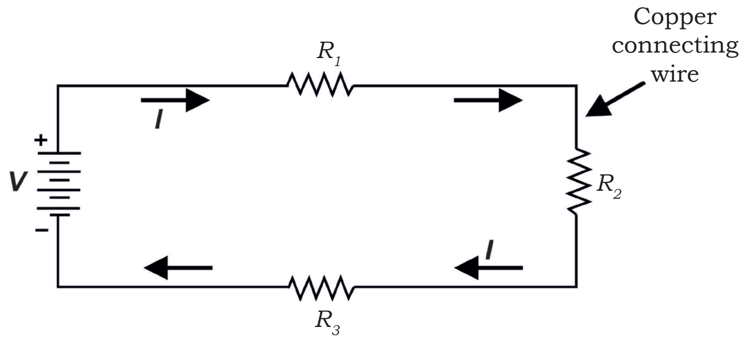


Fig. 1.22(a) Series circuit

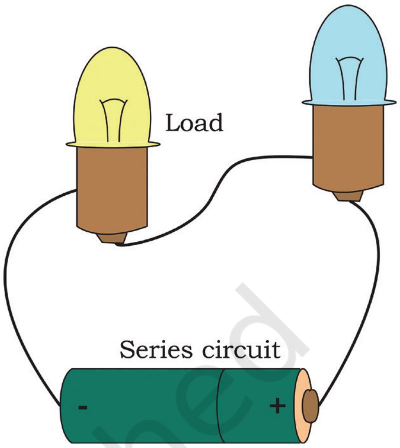


Fig. 1.22(b) Bulb connected in series circuit

The current I is assumed to be the flow of positive charge, and thus, flows out of the positive terminal of the battery, and through the external circuit, re-enters the battery at the negative terminal. This is indicated by arrows in Fig. 1.22(a).

In a series circuit, the total resistance, R_T is equal to the sum of the individual resistances. Thus, particularly, in case of Fig. 1.22(a), the battery sees total resistance, $R_T = R_1 + R_2 + R_3$, while in the general case of 'n' resistances connected in series, the total resistance is as follows:

$$R_T = R_1 + R_2 + R_3 + \ldots.. R_n$$

Parallel circuit

In a parallel circuit, electric load in the circuit forms multiple paths. Since, there are a number of paths, even if one electric load stops working, the other electric loads in the circuit will still work. The current from the source divides, so some of the current flows through one path and the rest through other paths. This means that the power source must supply more

current to power a parallel circuit than a series circuit, which may run down the battery faster. In a parallel circuit shown in Fig.1.23(a), the arrows represent the direction of current flow.

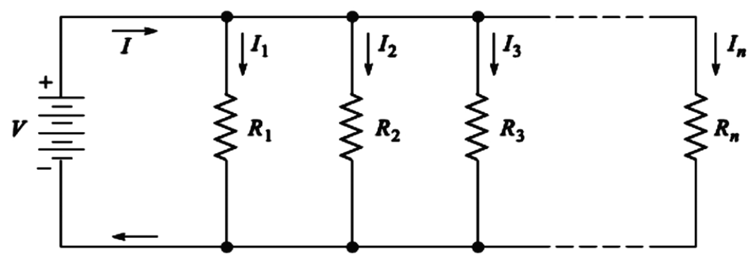
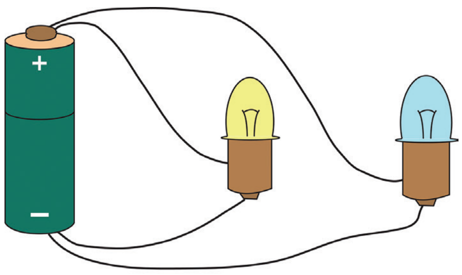


Fig.1.23(a) Parallel circuit



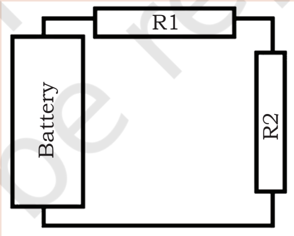
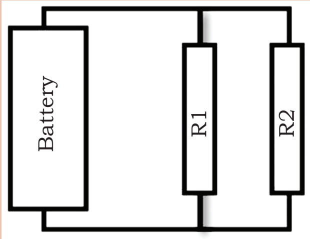
Parallel circuit

Fig.1.23(b) Bulbs connected in a parallel circuit

A parallel circuit is one, in which the battery current divides into a number of parallel paths. This is shown in Fig. 1.23(a), in which a battery of constant V volts delivers a current of I ampere to a load consisting of any number of n resistances connected in parallel.

Total resistance of the parallel circuit is as follows:

$R_T = (R_1 \times R_2 \times R_3 \times \ldots\ R_n)/(R_1 + R_2 + R_3 + \ldots\ldots + R_n)$

Key concept	Diagram
For a **series circuit**, R_1 is said to be in series with R_2. For these circuits, the current flowing through each device in series is the same. Adding the voltages across each element in series is equal to the total (battery) voltage.	 *Fig.1(a)*
For a **parallel circuit**, R_1 is said to be parallel to R_2. For these circuits, the voltage across each device in parallel is the same. Adding the current through each element in parallel is equal to the total (battery) current.	 *Fig.1(b)*

Activity

Draw and show more than one way to light a bulb. Can you do it with one wire? Can you do it with two wires? How many different ways can you think of?

Assignment 4

- Build series and parallel connections of resistors and calculate the resistance.
- Set up a circuit, in which three resistors of different values are connected in series and parallel. Then, manually calculate the value of total resistance in both series and parallel connections. Verify the values using an ohmmeter.

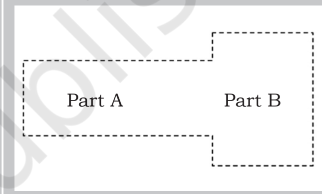
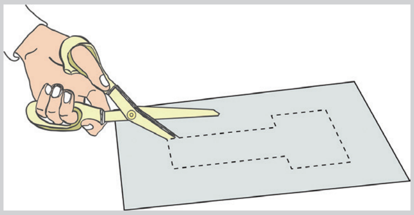
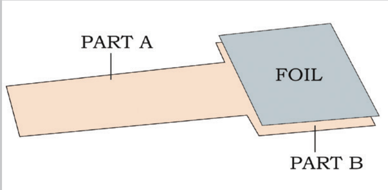
Practical Exercise 6

Making a bulb holder

Material required

Cardboard (thin) measuring 15×6 cm, aluminium foil measuring 6×4 cm, a pair of scissors, glue stick, push pin, pen, light bulb and tape

Procedure

Cut out the shape as shown in Fig. 1.	 *Fig. 1*
Lay the shape on top of the cardboard. Use a pen to trace around it, and then, cut the piece of cardboard as shown in Fig. 2.	 *Fig. 2*
Glue the piece of aluminium foil onto Part B of the bulb holder as shown in Fig. 4.	 *Fig. 3*

Use a push pin to poke a hole near the middle part as shown in Fig. 4. Part A uses a pen to widen the hole.

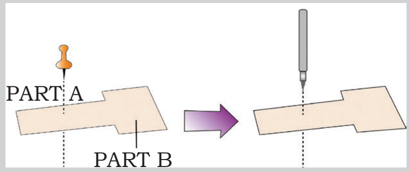


Fig. 4

Make sure the hole is large enough for the bulb to fit in. Then, loop Part A around the backside of Part B. Tape it into place as shown in Fig. 5.

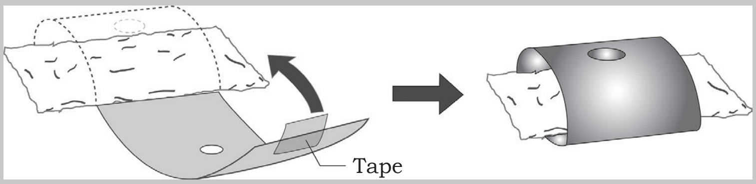


Fig. 5

Practical Exercise 7

Making an electric circuit using bulb holders

Material required

Bulb holder, light bulb, cardboard measuring 20 × 15 cm (8 × 6 inch), battery (C or D cell), two brads, push pin, pen, two connecting wires (stripped on each end), measuring 15 cm (6 inch) in length, electrical tape.

Procedure

1. Attach the battery to the cardboard circuit board by moving it down towards a narrow side of the cardboard.
2. Prepare to attach the bulb holder to the cardboard circuit board by using a push pin to poke holes in the bulb holder and the cardboard circuit board.
3. Use the tip of a pen to widen the holes, and then, use brads to lock the bulb holder in place on the circuit board as shown in Fig.1.

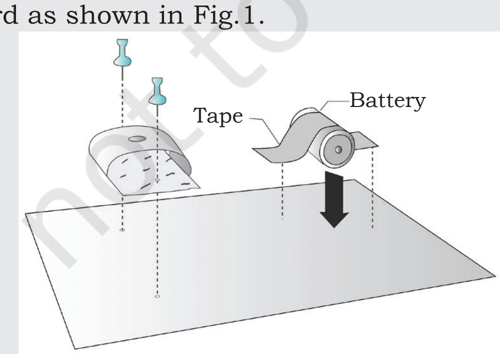


Fig. 1 Cardboard circuit

Notes

4. Tape one end of a connecting wire to the terminal of the battery. Wrap the other end around the bulb holder brad.
5. Tape one end of the other connecting wire to the battery's other terminal. Lay the other end into the bulb holder hole as shown in Fig. 2.

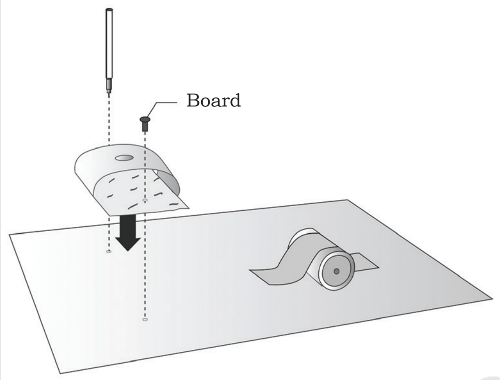


Fig. 2

6. Place the bulb into the bulb holder. Make sure the bottom of the bulb touches the aluminium foil as shown in Fig. 3.

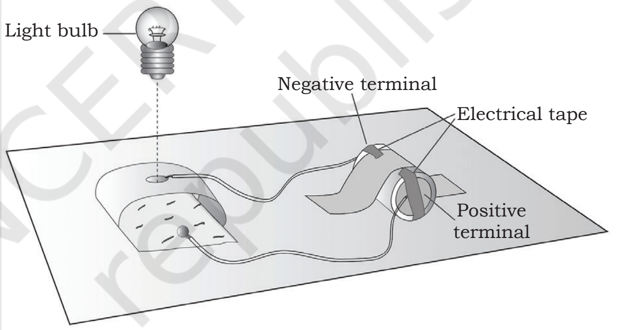


Fig. 3

Ohm's law

Georg Simon Ohm (16 March 1789–6 July 1854) was a German physicist and mathematician. As a school teacher, Ohm began his research with the new electrochemical cell. He investigated the relationship between current and voltage in a resistor and published his experimental results in 1827. Ohm's law can be used to understand the behaviour of electricity in individual components, as well as, in complete circuits.

Ohm's experiment

A DC variable supply voltage is connected with positive terminal at point 'a' and negative terminal at 'b' as

shown in Fig. 1.24. As voltage is increased, current recorded by the ammeter also increases. For every voltage value the current is recorded and the corresponding point is plotted on the rectangular graph. With this, a straight line graph passing through the origin is obtained in the first quadrant.

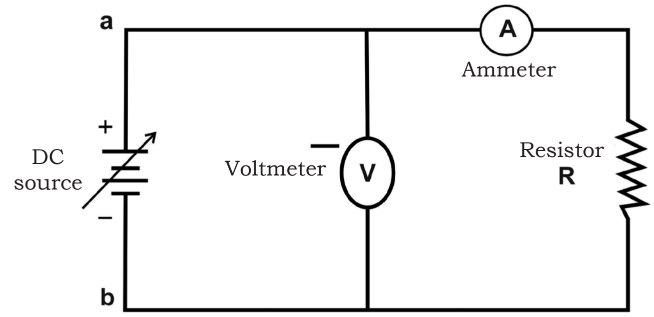


Fig. 1.24 Diagrammatic representation of Ohm's experiment

Next, terminals of the variable DC supply are interchanged, i.e., 'a' is connected to –ve polarity of dc supply and 'b' is connected to +ve polarity of dc supply. Since both the voltmeter and ammeter are moving coil meters, their individual connection should also be interchanged so that the meters can read up the scale.

This is done to reverse the direction of flow of current through the resistor R. Again, the voltage is varied and corresponding to each voltage, current is recorded and the pairs of V and I are plotted in the third quadrant.

Experiment results

The experiment results indicate that there is a linear relationship between current and voltage, both in the first and third quadrant. The slope of straight line is also same in both the quadrants, which shows that the potential difference across the terminals of the conductor is proportional to the current passing through it, i.e., V α I as shown in Fig. 1.25.

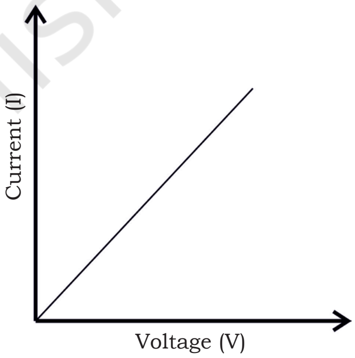


Fig.1.25 Linear relationship between voltage and current

Also, it is found that for a constant current in the conductor, resistance should be proportional to the potential difference, i.e., V α R.

Combining the two proportionalities, we have

V α IR

Or V= k (I × R)

where, k is a constant of proportionality. However, the units of voltage, current and resistance are defined, so that the value of k = 1. When the current is 1 amp and voltage is 1 volt, the resistance is 1Ω.

1 = k . 1 . 1

Thus, the equation becomes

V= IR

NOTES

Thus, the Ohm's Law states that "current is directly proportional to the applied voltage" or "the current in a conductor is directly proportional to the potential difference between the terminals of the conductor and inversely proportional to the resistance of the conductor".

It means that if voltage increases, current will increase, and if voltage decreases, current will also decrease. Also, if the voltage remains constant, as the resistance increases, the current goes on decreasing and vice versa. Therefore, when the voltage is constant, the resistance is inversely proportional to current. When resistance increases, current decreases, and if resistance decreases, current increases.

The above constitute is called Ohm's Law, if we let

'V' = voltage or EMF applied to the conductor

'I' = current flowing into the conductor

'R' = resistance of the conductor

With volts (V), current (I) in amperes and resistance (R) in Ohm, the Ohm's law is

$V = IR$

Practical Exercise 8

Verify Ohm's law in the given electrical circuit.

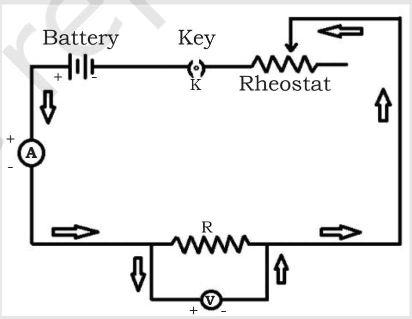


Fig. 1. Circuit diagram of Ohm's law

Material required

Rheostat, resistor, ammeter, voltmeter, voltage supply of 5V DC

Procedure

1. Using the DC circuit trainer, connect the circuit as shown in Fig.1.
2. Connect the variable voltage supply to both the ends of the rheostat as shown in the circuit diagram.
3. Connect the ammeter in series of the rheostat as shown in the circuit diagram.

4. Connect the voltmeter in parallel of the rheostat as shown in the circuit diagram.
5. Now, start measuring the voltage and current by varying the position of the rheostat knob from minimum to maximum position.
6. When the rheostat knob is at minimum position, maximum current will flow through the circuit and vice versa.
7. Increase the voltage from 0–10 v and measure the current at each step, and then, record it in the table given below.

V (Volt)	0	1	2	3	4	5	6	7	8	9	10
1 (mA)											

8. Observe the number of readings and fill them in the table.
9. Now, with this data, plot a graph between voltage and current.

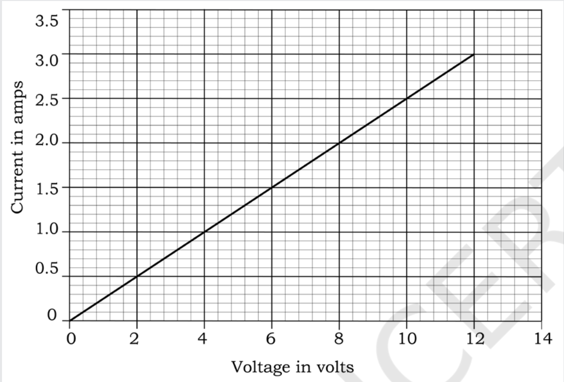


Fig. 2

10. The graph between voltage and current will be linear (Fig. 2), i.e., there will be proportionality in voltage and current. If the voltage increases due to any factor, then the current will also increase with the same value.

The relationship between current, voltage and resistance is important for all electrical networks.

	Current	Voltage	Resistance
Symbol	I	V	R
Unit	Ampere (A)	Volt (V)	Ohm (Ω)

Problems in Ohm's law

Some of the solved examples to understand the Ohm's Law better are as follows.

Example 1: A 10 V battery is connected to an electric bulb of 20 Ohm resistance. Find the current flowing through the electric bulb.

Notes

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Solution: Here,

V= 10 V

R = 20 Ω

The current flowing through the electric bulb is given by

V = I R

I = V/R

I = 10/20

I = 0.5 ampere, so the current flowing through the bulb is 0.5 ampere.

Example 2: An electric iron of resistance 40 Ω is connected to a supply voltage. The current flowing through the electric iron is 6 ampere. Find the voltage applied to the electric iron.

Solution: Here, I = 6 A, R = 40 Ω

Voltage equation is given by

V = I R

So, voltage is expressed as V = 6 × 40

V = 240 volts

Example 3: A 110 V voltage source supplies power to a halogen light. The current flowing through the halogen light is 5 A. Find the resistance of the halogen light.

Solution: Here, V=110V, I=5A

The resistance is given by

R = V / I

R = 110/5

R = 22 Ω

So, the resistance of Halogen light is 22 Ohm.

Assignment 5

A. Solve the problems based on Ohm's law.

1. A voltage of 9 Volt is applied across a 3 Ohm resistor. Calculate if current is flowing.
2. A 6 Ohm resistor passes a current of 2 amps. What is the voltage across it?
3. What is the voltage of a circuit with a resistance of 255 Ohm and a current of 3 amp?
4. A small electrical pump is labeled with a rating of 5 amp and a resistance of 30 Ohm. At what voltage is it designed to operate?

5. A 9 Volt battery is hooked up to a light bulb with a rating of 2 Ohm. How much current passes through the light bulb?
6. A lamp is plugged into a power socket, which provides 110 volt. An ammeter attached to the lamp shows 2 amp flowing through the circuit. How much resistance is the lamp providing?
7. If your skin has a resistance of 9000 Ohm and you touch a 9 Volt battery, how much current will flow through your body?
8. How much current will flow through your body with a skin resistance of 12,000 Ohm, if you touch a 120 Volt house potential?
9. Suppose you are soaked in seawater and your resistance is lowered to 1000 Ohm. Now, how much current will flow through your body if you touch a 9 Volt battery?
10. When you are soaked in seawater, how much current will flow through your body if you touch a 120 Volt house potential?

B. Write the electrical symbols and units for the following.

	Current	Voltage	Resistance
Symbol			
Unit			

C. In the following table, from the given quantities, calculate the unknown quantities. The unit 'k' stands for kilowatt, which means 1000 watts.

Voltage	Current	Resistance	Power
100 V	5A		
12 V		1 Ohm	
	5A	8 Ohm	
230 V	13A		
	3A	150 Ohm	
50 V		20 Ohm	
		40 Ohm	1 kW
	0.5 A		2.5 W
250 V			62.5 W

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D. Find the electrical quantities in the circuit as shown in Fig. 1.
   1. Calculate the equivalent resistance of this circuit.
   2. Calculate the total current drawn.

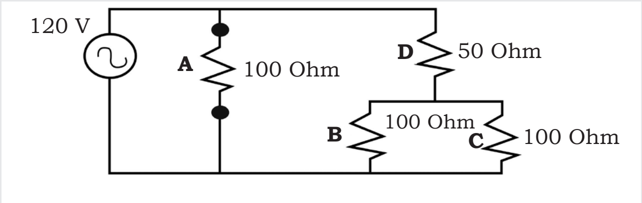

Fig. 1

   3. Calculate the voltage across following:
      Resistor 'A' ....
      Resistor 'B' ....
      Resistor 'C' ....
      Resistor 'D' ....
   4. Calculate the amount of power consumed by the circuit.

E. Find the following quantities for the circuit in Fig. 2.
   1. Calculate the voltage across each load when the switch is open.
   2. Calculate the current drawn from the battery.
   3. Calculate the voltage drop across each resistor.
   4. Calculate the equivalent resistance in the circuit.

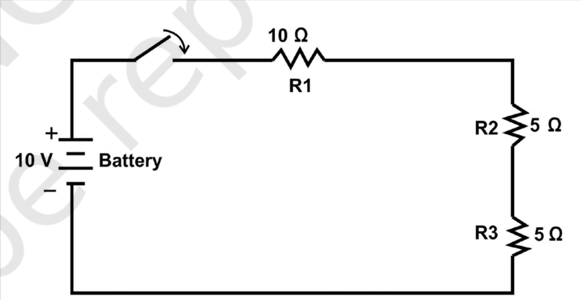

Fig. 2

Kirchhoff's laws

These laws are named after Gustav Kirchhoff, a German physicist. Kirchhoff defined the basic relationship between voltage (V) and current (I). These laws of Kirchhoff are used for circuit analysis. Kirchhoff's laws relate to the conservation of energy, which states that energy cannot be created or destroyed but only changed to different forms. This can be expanded to laws of conservation of voltage

and current. In any circuit, the voltage across each series component (carrying the same current) can be added to find the total voltage. Similarly, the total current entering a junction in a circuit must be equal to the sum of the current leaving the junction. Kirchhoff's law is classified as:

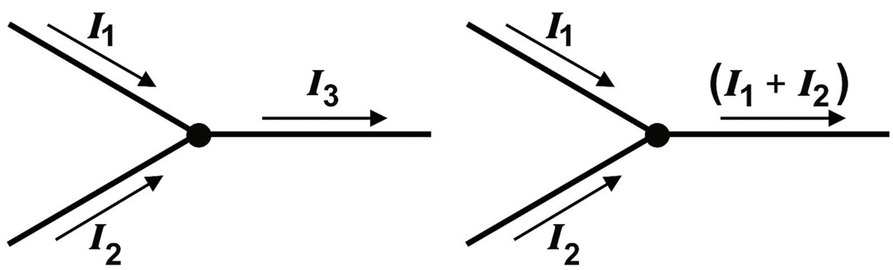

Fig. 1.26 Kirchhoff's current law

1. Kirchhoff's current law
2. Kirchhoff's voltage law

Kirchhoff's current law

Kirchhoff's current law states that total incoming currents at a point is equal to the total outgoing current. It can be understood by an example. Consider that I_1 and I_2 are coming towards a point. Current I_1 and I_2 are incoming current as they are coming towards a point as shown in Fig. 1.26. Current I_3 is outgoing current with respect to the point. The sum of incoming current I_1 and I_2 is equal to the sum of outgoing current I_3.

Mathematically, at a point

$$I_1 + I_2 = I_3$$

In a series circuit, the total current flowing remains the same at any point (Figs. 1.27 and 1.28).

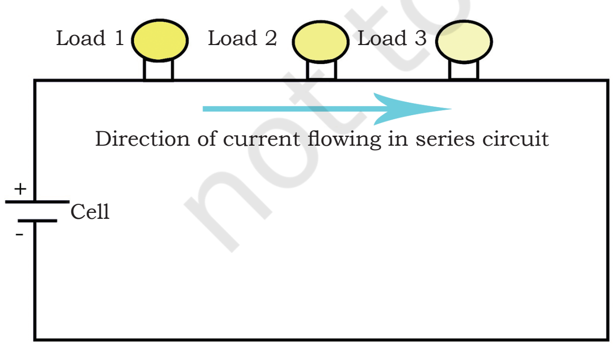

Fig. 1.27 Loads connected in a series circuit

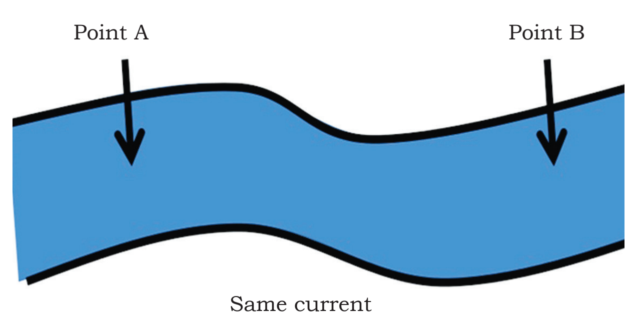

Fig. 1.28 Analogy of current in series circuit

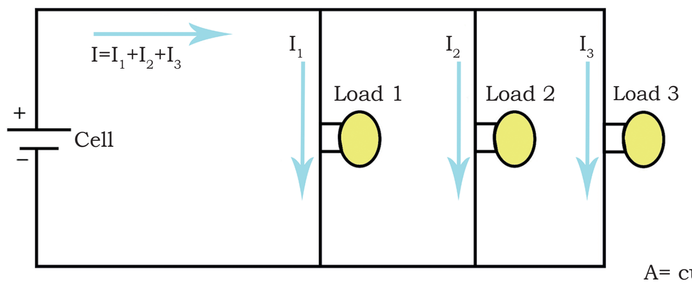

Fig.1.29 Loads connected in a parallel circuit

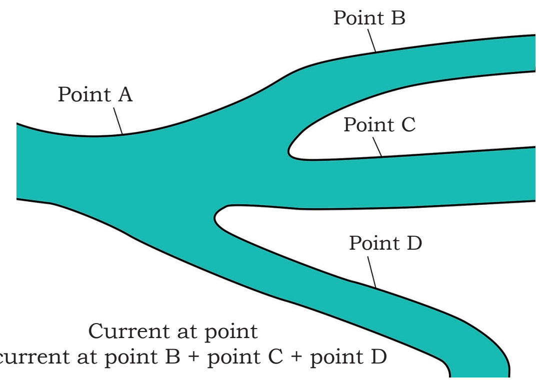

Fig. 1.30 Analogy of current in parallel circuit

In a parallel circuit, the total current flowing in the circuit is divided in parallel branches (Figs. 1.29 and 1.30).

Kirchhoff's voltage law

Kirchhoff's voltage law states that total voltage drop across the loads in a circuit is equal to the total voltage applied to the circuit. In other words, it states that the algebraic sum of the product of currents and resistance in each of the conductors in any closed path (or mesh) in a network plus the algebraic sum of the EMF in that path is zero.

In other words, $\sum IR + \sum EMF = 0$

Let us now write the equation for Fig. 1.31 in accordance with Kirchhoff's voltage law. To do this, we start at any point and move completely around the circuit, listing the 'voltage drops' and the 'voltage rises' as we proceed (in doing this, remember that we have defined that going from 'minus to plus' constitutes a RISE in voltage and going from 'plus to minus' constitutes a DROP in voltage). Thus, if we agree to list all 'voltage drops' on the left-hand side of our equations and all 'voltage rises' on the right-hand side, the Kirchhoff's voltage equation for Fig.1.29 will be: $R_1I + V_2 + R_2I = V_1$

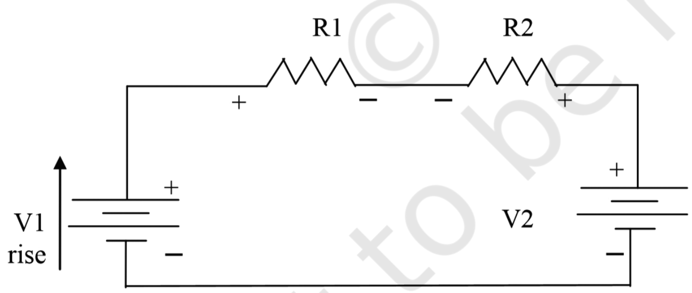

Fig. 1.31 Circuit diagram for Kirchhoff's voltage law analysis

Note, that V_2 appears as a voltage drop as we go through the battery from plus to minus (+ to –). Alternatively, putting all battery voltages on the right-hand side, the above equation becomes

$R_1I + R_2I = V_1 - V_2$.

Hence, $I = (V_1 - V_2)/(R_1+R_2)$

It can be understood with an example. Consider a circuit, in which three loads are used, i.e., R_1, R_2, R_3. Total applied voltage to the circuit is V. Voltage drop across the loads are V_1, V_2, V_3. Therefore, according to Kirchhoff's voltage law, the total applied voltage (V) is equal to the sum of individual voltage drop (V_1, V_2, V_3) across the loads.

Mathematically,

$V=V_1+V_2+V_3$

As shown in Fig. 1.32, the voltage drop across the loads are 5V, 2V, 3V. The total applied voltage is 10V.

10V = 5V + 2V + 3V

In a parallel circuit, the total voltage provided by the source is equal to the voltage across each parallel branch.

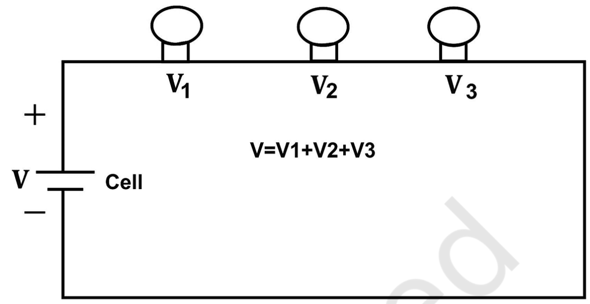

Fig. 1.32 Electric circuit with series connected loads

Analogy

Fig. 1.33 Analogy of voltage in series circuit

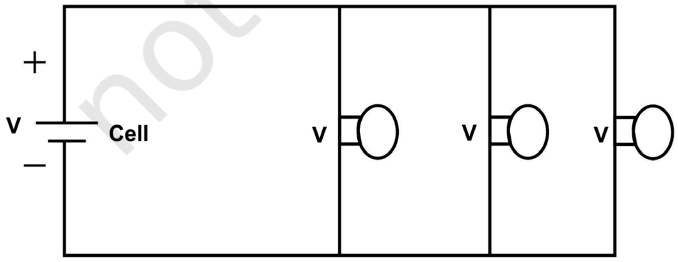

Fig. 1.34 Parallel circuit

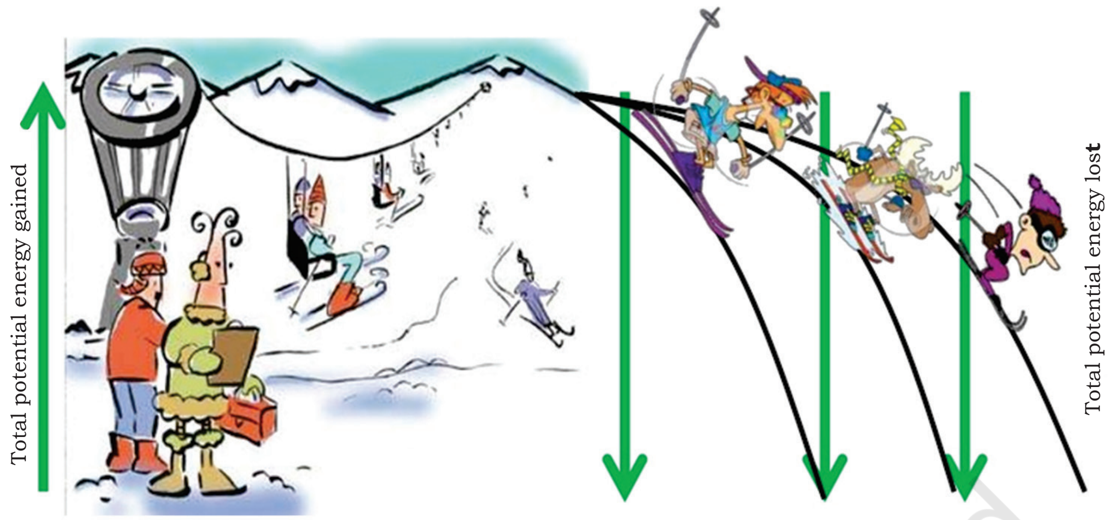

Fig. 1.35 Analogy of voltage in parallel circuit

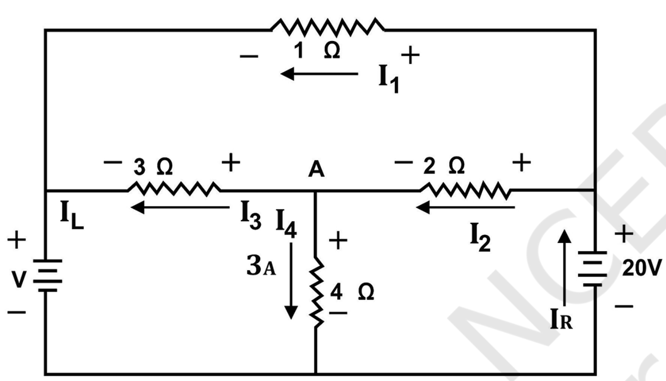

Fig. 1.36 Diagrammatic representation of Kirchhoff's law

Analysis of Kirchhoff's law

Analyse the circuit given in Fig.1.36 with 3A of current running through the 4Ω resistor and

- determine the current passing through the other resistors.
- determine the voltage of the battery on the left.
- determine the power delivered to the circuit by the battery on the right.

Procedure

Identify the current through the resistors by the value of the resistor (I_1, I_2, I_3, I_4) and the current flowing through the batteries (I_{Left} and I_{Right}).

Start with the 2Ω resistors. Apply the loop rule to the circuit on the lower right.

$$20\text{ V} = I_2(2\Omega) + (3\text{A})(4\Omega)$$

$$I_2 = 4\text{A}$$

Start circuit analysis from 3Ω resistors. Apply the junction rule at point A in the centre of the circuit.

$$I_2 = I_3 + I_4$$

$$4\text{A} = I_3 + 3\text{ A}$$

$$I_3 = 1\text{ A}$$

- The current through 1Ω resistor certainly runs from right to left. If we apply the loop rule to top circuit, we will have to run against that current. This changes what is normally considered as a potential drop into a potential increase.

$$I_1(1\Omega) = (4A)(2\Omega)+(1A)(3\Omega)$$
$$I_1 = 11A$$

- Apply the loop rule to the outer circuit to get the voltage of the battery on the left (continuing with the assumption that the current is running counter clockwise). We find ourselves running through the left battery backwards. This changes what is normally considered as a higher potential to a lower potential.

$$20V = (11A)(1\Omega)+V_L$$
$$V_L = 9V$$

- Let us verify this result by repeating the procedure for the bottom circuit.

$$20\text{ V} = (4A)(2\Omega)+(1A)(3\Omega)+V_L$$
$$V_L = 9\text{ V}$$

- The power delivered to the circuit by the battery on the right is the product of its voltage and the number of times current drives around the circuit. We already have the voltage (it is given in the problem). All that remains is to determine the current. Apply the junction rule to the junction on the left.

$$I_L = I_1+I_3$$
$$I_L = 11A+1A$$
$$I_L = 12A$$

and again to the junction at the bottom

$$I_R = I_L+I_4$$
$$I_R = 12A+3A$$
$$I_R = 15A$$

- To find the power of the battery on the right

$$P = VI$$
$$P = (20V)(15A)$$
$$P = 300W$$

Notes

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Assignment 6

1. Determine the current through each resistor in the circuit shown in Fig. 1

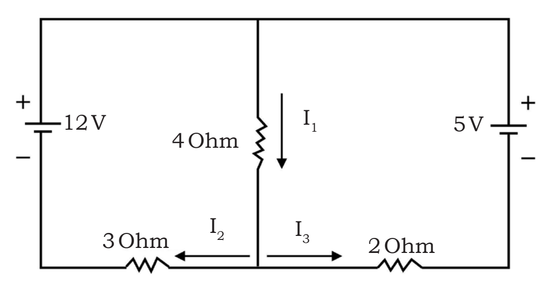

Fig. 1

2. Verify Kirchhoff's law by observing the reading in ammeter and voltmeter as shown in Fig. 1.

Practical Exercise 9

Material required

DC trainer kit of KVL and KCL, connecting cords and power supply

Procedure

1. Using the DC circuit trainer, connect the circuit shown below.

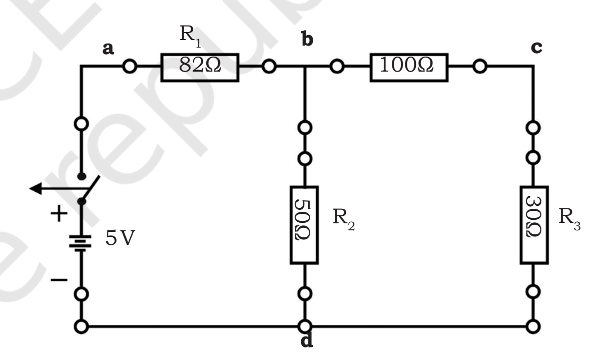

Fig. 2

2. Measure the values of voltage and current of each resistor in the circuit and record it in the table given below.

	R_1(Ohm)	R_2(Ohm)	R_3(Ohm)	R_4(Ohm)
I (mA)				
V (Volt)				

3. Measure the voltage and current values across the resistors R_1, R_2, R_3 and R_4. Note the reading in the table. Observe the total voltage applied in the circuit and the voltage drop across individual resistors.

4. If total applied voltage in the circuit and voltage drop across the individual resistor are equal, then we can say that Kirchhoff's voltage law is verified.

NOTES

Energy consumption in home appliances

Calculation of energy

To calculate the energy consumption of home appliances, the following technique is used. We know that

Power = Energy/Time

or

Energy = Power × Duration of Usage (Time)

By modifying this formula slightly, we can determine the energy consumption per day.

Energy consumption/day = Power consumption × hours used/day

Where,

(a) Energy consumption will be measured in kilowatt hours (kWh) like on your utility bills.

(b) Power consumption will be measured in Watt.

(c) Hours will be the actual time for which you use the appliance every day.

Since we want to measure energy consumption in kilowatt hours, we must change the way power consumption is measured from watt to kilowatt (kWh). We know that 1 kilowatt hour (kWh) = 1,000 watt hours. So, we can adjust the formula given above to

Energy consumption/day (kWh) = Power consumption (watts/1000) × hours used/day

Example 1: Calculating energy use of a ceiling fan

Solution: If you use a ceiling fan (200 watts) for four hours per day for 120 days a year, what would be the annual energy consumption?

Use this formula.

Energy consumption/day (kWh) = Power consumption (watts/1000) × hours used/day

Energy consumption per day (kWh) = (200/1000) × 4 (hours used/day).

Notes

Energy consumption per day (kWh) = (1/5) × 4 energy consumption per day (kWh) = 4/5 or .8. So, the energy consumption per day is .8 kWh. To find out energy for 120 days, do simple multiplication.

.8 × 120 = 96 kWh

Check Your Progress

A. Multiple choice questions

1. Which of the following components is used to close or break the circuit?
   (a) Bulb
   (b) Switch
   (c) Wire
   (d) Electric cell
2. Which of the following components is used to provide resistance?
   (a) Heat
   (b) Energy
   (c) Product
   (d) Resistor
3. The frequency (f) of alternating current is ________ Hertz in India.
   (a) 45
   (b) 60
   (c) 50
   (d) 55
4. In a series circuit, current remains ____________ and voltage ____________.
   (a) divided, same
   (b) same, same
   (c) divided, divided
   (d) same, divided
5. In a parallel circuit, current is ____________ and voltage remains the ____________.
   (a) divided, same
   (b) same, same
   (c) divided, divided
   (d) same, divided
6. The amount of work done in one second is called ________.
   (a) power
   (b) current
   (c) voltage
   (d) charge
7. Ohm's law states that _______________.
   (a) voltage is directly proportional to the applied voltage
   (b) voltage is directly proportional to the applied current
   (c) current is directly proportional to the applied voltage
   (d) current is directly proportional to the applied current

8. The amount of charge flowing through a point in one second is called ______________.
(a) voltage
(b) current
(c) power
(d) charge

9. The amount of work required to move a unit coulomb charge from point A to point B called ___________.
(a) current
(b) charge
(c) voltage
(d) power

10. What are the basic building blocks that all matter is composed of?
(a) electrons, neutrons and protons
(b) electrons, protons and ions
(c) neutrons, protons and ions
(d) electrons, neutrons and charged ions

11. Electric charge can be produced by ______________.
(a) sticking
(b) rubbing
(c) oiling
(d) passing AC current

12. An electron has _____________ charge.
(a) positive
(b) negative
(c) zero
(d) sometimes positive, sometimes negative

13. A proton has ____________ charge.
(a) positive
(b) negative
(c) zero
(d) sometimes positive, sometimes negative

14. A neutron has ____________ charge.
(a) positive
(b) negative
(c) zero
(d) sometimes positive, sometimes negative

15. The unit of electric current is ____________.
(a) ampere
(b) volt
(c) watt
(d) joule

16. The unit of electrical power is ________________.
(a) volt
(b) watt
(c) joule
(d) ampere

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17. The term used to designate electrical pressure is ________________.
    (a) voltage
    (b) watt
    (c) joule
    (d) ampere
18. The statement, which correctly represents Ohm's law, is ______________.
    (a) V = IR
    (b) V = R/I
    (c) R = VI
    (d) I = R/V
19. If V = 50 V and I = 5 A, then R = _____?
    (a) 50 Ω
    (b) 5 Ω
    (c) 10 Ω
    (d) 2 Ω
20. If P = 50 W and R = 2 Ω, then I = _____?
    (a) 50 A
    (b) 5 A
    (c) 10 A
    (d) 2 A

B. Fill in the blanks

1. In __________ circuit, current remains the same and voltage divided.
2. In __________ circuit, current is divided and voltage remains the same.
3. The amount of __________ done in one second is called power.
4. A component used to close or break a circuit is __________.
5. Proton has __________ charge.
6. The unit of electrical __________ is watt.
7. "Current is directly proportional to the applied voltage." This law is given by __________.
8. 1kWh = __________ watt × __________ second.
9. Switch is used for __________ and ____________ of circuit.
10. Electrons have __________ charge.
11. The relationship between voltage, current and resistance by Ohm's Law.
    Voltage = Current × Resistance
    This will mean that
    $I = \frac{V}{R}$ Current = __________ ÷ __________
    and $R = \frac{V}{I}$ __________ = __________ ÷ _________

C. State whether the following statements are True or False

1. The frequency (f) of alternating current is 60 hertz in India.
2. Electrons are electrically neutral.
3. Due to rubbing of two bodies, electric charge is produced.
4. The relationship between voltage, current and resistance is given by Kirchhoff's law.
5. The unit of current is ampere.
6. Resistor easily passes current.
7. The unit of voltage is watt.
8. The unit of power is joule/second.
9. Current in a circuit is due to applied voltage.
10. 1kWh = 1000 watt × 3600 seconds.

D. Short answer questions

1. What is volt?
2. What is the supply frequency of supply voltage?
3. What is electric current?
4. What does 10A mean?
5. Explain diagrammatically how the components are connected in a series circuit.
6. Explain diagrammatically how the components are connected in a parallel circuit.
7. What will happen to a series circuit if a bulb gets fused? Will the circuit be close in this case?
8. List an appliance where resistors are used.
9. What are different variable resistors?
10. How are AC and DC currents different from each other?
11. List appliances that use DC power.
12. (a) Calculate the resistance 'R' in the circuit (Fig. 1).

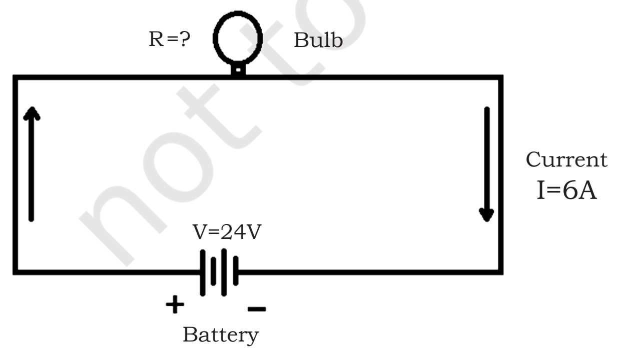

Fig. 1

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(b) Calculate the voltage 'V' in the circuit (Fig. 2).

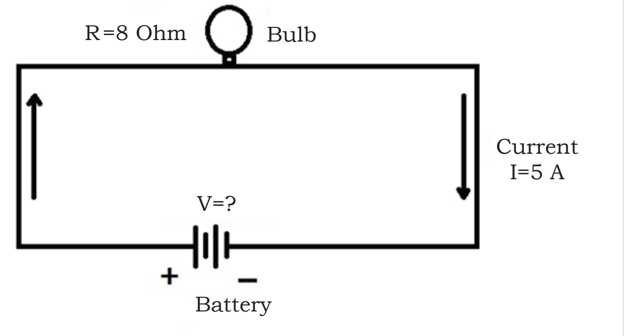

Fig. 2

(c) Calculate the voltage 'V' in the circuit (Fig. 3).

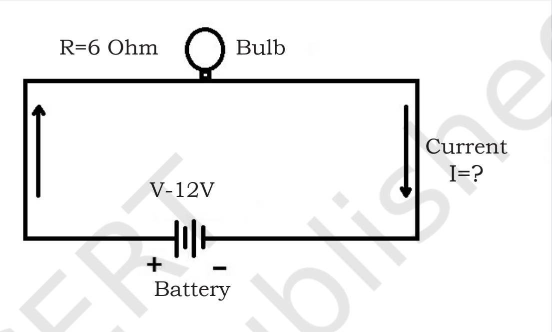

Fig. 3

(d) Verify the KCL and KVL and find I_1, I_2, I_3 for Fig. 4.

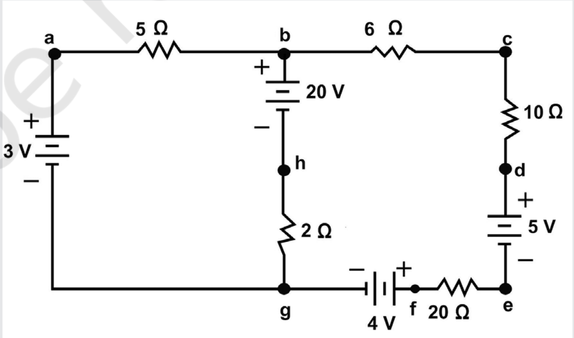

Fig. 4